THE JOULE-THOMSON EFFECT IN AIR

By

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Approved by:

F. E. Kester

August, 1928. Head of Department.

Introduction

This work was undertaken with the hope of making a new determination of the Joule-Thomson effect in air and, after the accuracy of the method and apparatus had been assured, of extending the work to other more important but less readily available gases. In common with other experimenters in this field it was found, however, that preliminary work and the overcoming of unforseen difficulties took so much time that the work had to be limited to air and to narrow ranges of pressure and temperature.

While the results obtained so far are inconclusive and of little value as a basis for comparison with the determinations of other experimenters, it is hoped that this preliminary work may lead to further results that may be both consistent and accurate.

In presenting this subject as a thesis the writer is making no attempt to claim ~~either~~ entire credit for any part of the work that may later prove of value. Neither does he claim to have finished the piece of work he set out to do. Dr. F. E. Kester has had the project in mind for quite a number of years and has had the apparatus nearly ready for operation several times. The press of other work has, however, prevented his giving the necessary time to the undertaking and it has languished a result. It was with the hope of finally getting some tangible results that the interest of the writer was enlisted. To Dr. Kester, then, belongs the credit for the inception of this project, for the design and construction of the apparatus, and for more than an equal share of the time spent in the more recent part of the work.

An excellent and, so far as the writer has been able to ascertain, complete summary of the experimental and theoretical work on the Joule-Thomson effect to date was prepared by L. G. Hoxton[1] and published in 1919. E. S. Burnett's[2] work on Carbon Dioxide and J. R. Roebuck's[3] work on air were published in 1923 and 1925 respectively. Roebuck compares the results of four observations, the original work of Joule and Thomson in the years 1852 to 1862, that of Noell in 1914 to 1916, that of Hoxton, published in 1919 and his own in 1925. So far as the writer knows, no other important work has been done on air or any of the gases except carbon dioxide. Even the briefest study of the results just mentioned or even of those on carbon dioxide show an alarming range of descrepancies between values obtained. Hoxton and Roebuck working with what seems to be essentially similar apparatus and with equally great care and attention to details to insure accuracy, obtained results differing by as much as 27%. There is obviously, a need for more work along this line. So far the original results of Joule and Thomson seem as good as any for any of the gases since experimented with and their work has not even been approached in the extent of the field covered. This is surprising when the great advance, since the date of their work, in precision of measurements in other fields is considered. Both Hoxton and Roebuck worked with the so-called "radial-

1. Phys. Rev. (2) 13, 438, 1919.
2. Phys. Rev. (2) 22, 590, 1923.
3. Proc. Am. Acad. 60, 13, 1925.

flow" plug and both used platinum resistance thermometers to measure temperature differences.

Just where the difficulty in obtaining results consistent with those of other observers lies is hard to surmise. Although the cooling effect expected is rather small it is well within the scope of present day accuracy of measurement. The experiment is essentially the same as that conceived and performed by Joule and Thomson in their pioneer work. It consists of allowing air under pressure to expand through a porous plug into a region of lower pressure and of measuring the change in temperature produced. It would seem to be a perfectly straightforward process. Enough difficulty has been met with in the present work, however, to convince the writer that extraordinary care in the design of apparatus and an unusual amount of patience in procedure together with almost unlimited time are necessary for success in obtaining reliable results.

Apparatus.

The apparatus used in the present experiment is similar in design to that used by Dr. Kester[4] in his earlier work with carbon dioxide. Numerous changes have been made, however, so that a complete description of the apparatus will be necessary. The "axial flow" type of plug and the use of thermo-couples for the measurement of temperature differences have been adhered to.

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4. Phys. Rev. 21, 4, 1905.

Figure I shows the general plan of the apparatus set up. The compressor C was so designed that air could be taken in from the outside through intake I or from the low pressure cylinder B and compressed into the high pressure cylinder A. A and B are iron cylinders about 8 feet long and 1 foot in diameter. The intake I is at the end of a $1\frac{1}{8}$ inch iron pipe which was filled with lump caustic potash for the removal of carbon dioxide and part of the water from the air. In preparing for a run the compressor was operated with the intake and high pressure cylinder valves open and the valve to the low pressure cylinder closed. After sufficient air had been drawn into the system, the intake valve was closed and the low pressure cylinder was connected to the pump. The valve V on the other end of the cylinders was adjusted so that the flow of air from the high pressure side of the system to the low pressure side would be balanced by the action of the compressor.

From the high pressure cylinder the air was carried through the U-shaped drying tube, the output arm of which was filled with phosphorus pentoxide. Only one arm of the tube was filled with the drying material to prevent clogging of the tube by the pentoxide as it absorbed moisture from the air.

From the drying tube the air passed through a needle valve into a small cylinder which was designed to act as an equalizing reservoir. In view of the size of the iron cylinders A and B previously mentioned, this small cylinder might seem unnecessary. However, the pressure in A was always higher than that actually transmitted to the plug. The small cylinder served therefore in equalizing the pressure in the system beyond the needle valve.

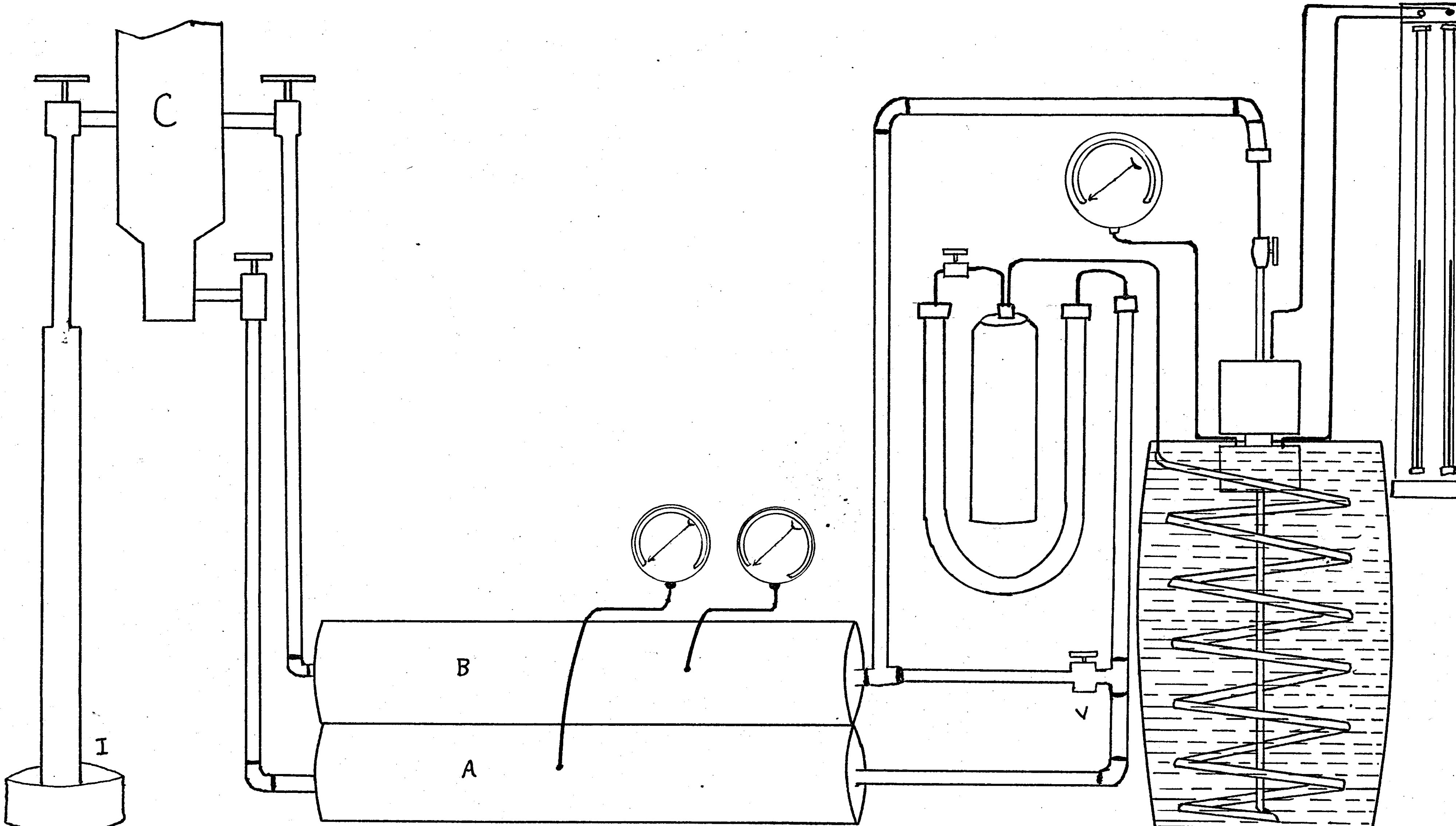


Fig. 1

From the equalising chamber the air was led through a copper tube 10 mm. in inner diameter, 1.25 mm. in wall thickness and about 8 m. long. The tube was wound, as shown, in spiral form and immersed in a water bath. A wooden barrel served as a vessel to contain the water and to support the apparatus. To prevent stream-line effects in the air as it passed through the copper spiral, the tube had been threaded with steel lathe turnings before it had been formed into the spiral.

The porous plug was situated just above the water line of the barrel. After passing through the plug the air passed through another needle valve and was carried back to the low pressure cylinder B.
The construction of the "nozzle" which contained the plug is shown in detail in Figure 2. The plug itself was made of 2.8 grams of clean cotton fiber and packed tightly into a slightly tapering tube of red fiber insulating material. The friction between the cotton plug and the walls of the tapering tube was sufficient to hold the plug in place. This fiber tube was about 13 cm. long, 1 cm. in diameter at lower end and 8 mm. diameter at upper end. Around this central tube, which was designed as the main gas path, was a loosely fitting larger tube of the same material. This left an annular space, which was tightly packed with cotton string in the region immediately surrounding the plug. The purpose of this annular space and string packing was to provide a thermal "guard ring" for the plug itself. It was thought that the relatively small quantity of air passing through the string packing would suffer the same cooling effect as that through the plug proper and that the insulation of the main gas path would be greatly improved.

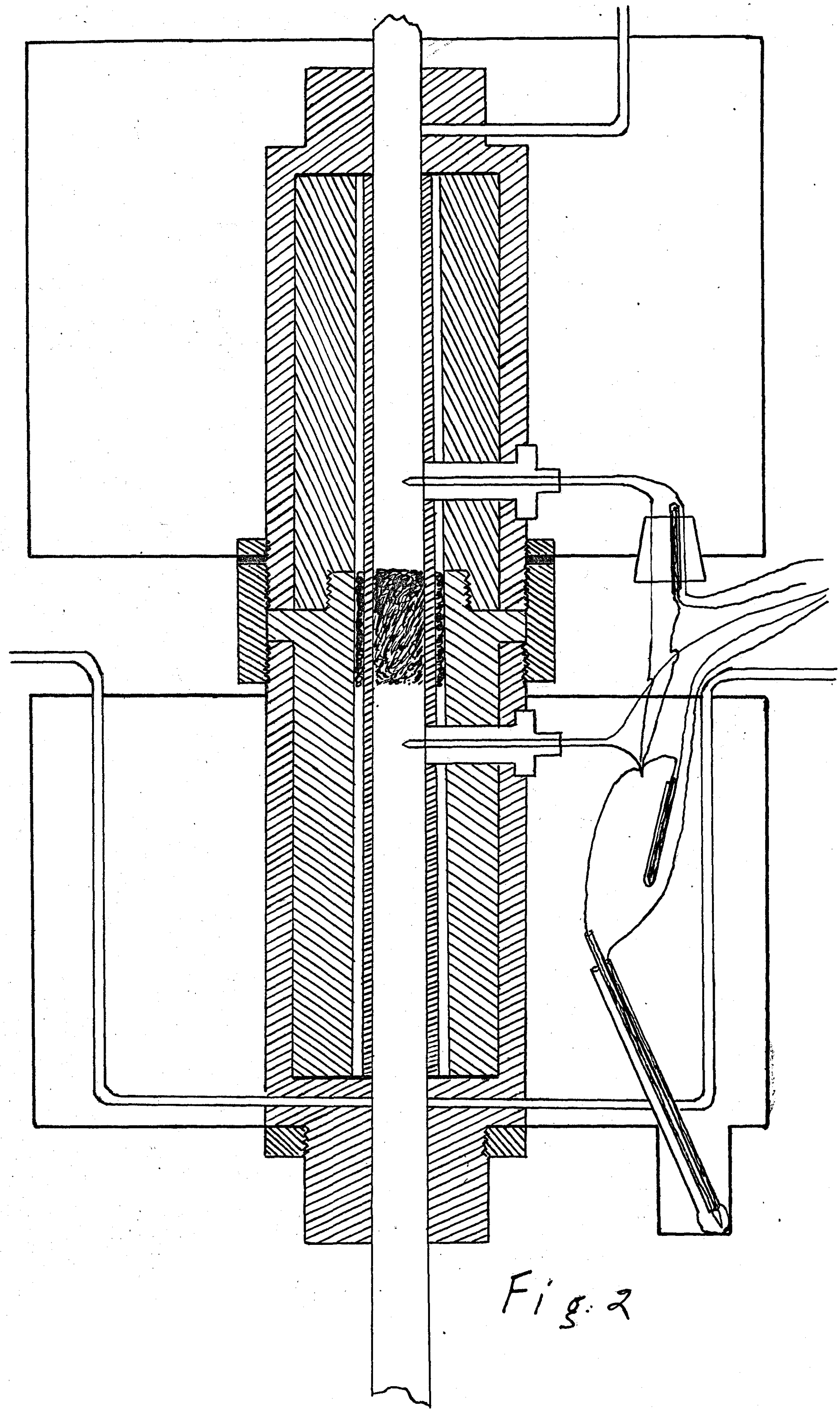


Fig. 2

The main fiber nozzle which surrounded the annular space was made in two sections as shown and screwed together by means of threads cut into the fiber itself. No packing was used at this joint, since the fit of the two parts of the nozzle seemed to be sufficiently tight to preclude the possibility of any gas leading through. This assumption was found to be erroneous when the apparatus was taken apart and later determinations were made with the joint packed with rubber packing.

Surrounding this fiber nozzle was a cylinder of brass, made in two sections and fastened at the middle by a steel screw ring. A shoulder of the fiber nozzle separated the two parts of the brass cylinder. Small tubes connected the gas path to the manometer and pressure gauge.

Separate oil baths surrounded the upper and lower parts of the nozzle. These were held in place by screw rings as shown. Each oil bath and the water bath were provided with stirrers operated by a small electric motor.

Two holes through one side of the nozzle admitted the thermo-electric junctions to the gas path. These were made of copper and constantan wires, o.14 mm. and 0.13 mm. in diameter respectively. They were carried through plugs of bakelite into which they were cemented with a mixture of litharge and glycerine. The bakelite plugs were held in place by steel clamping rings not shown in the figure. Lead washers served as packing.

Besides the two main gas path junctions, thermocouples were used to check on the temperature of the various baths. Five junctions were used - the two already mentioned and one for each of the baths, the large water bath, the lower oil bath and the upper oil bath. The constantan wires were all led to a common junction which was kept immersed in the lower oil bath. The five copper wires were led to the measuring device. The electrical circuits are indicated in Fig. 3.

The emfs involved were measured by the modified potentiometer method described by Dr. Kester. The five thermo-electric junctions used formed four thermocouples for the measurement of temperature differences. The lower gas path junction in the above arrangement could be made to act with either of the other four by means of the proper switch or key. A better, or at least more convenient arrangement could have been obtained if the upper main junction had been made the point of reference. This would have made it possible to secure an adjustment of temperature of the upper bath and the gas above the plug without a constant shift of switches.

The same mercury switch as previously used by Dr. Kester is indicated at S. The upper bath and upper gas path junctions were attached to this switch. Key 1 is a short circuiting key for the galvanometer. This was considered necessary to obtain the true zero of the instrument. In practice, the zero used as representing the position of no emf. in the thermocouples was taken as midway between the short circuited zero and the "mechanical" or open circuit zero. This was the best estimate of the true zero that could be obtained when the main junctions were kept at the same temperature for considerable periods of time. Keys 2 and 3 were in the circuits of the lower oil bath and water bath junctions.

The galvanometer was a Leeds and Northrup high sensitivity instrument, resistance 12 ohms. It was set about 125 cm. from the scale and was very satisfactory except that it proved very sensitive to thermal effects. It was found necessary to shield it very carefully from air currents to keep it from behaving in an erratic manner. The galvanometer as well as all switch connections and the potentiometer wire were covered with cotton wrappings and cardboard shields.

The potentiometer circuit included besides the potentiometer wire of fixed length A B, a dry cell, a dial resistance box, and a milli-ammeter produced by tapping a Weston voltmeter so that the current passed through the movable coil of the instrument only.

This Weston instrument showed a most remarkable constancy in its readings. It had been calibrated by Dr. Kester in 1916 and the scale readings found to be proportional to the current flowing within the limits of the accuracy of observation. This was done by measuring by means of a potentiometer the emf drop across a 200 ohm resistance coil of a Wolff Box, for various scale reading of the instrument. As an example of the values obtained the following is cited. For a scale reading of 149.3 the potential difference was 1.5678 volts, indicating a current of $\frac{1.5678}{200}$ or .007839 amperes. In

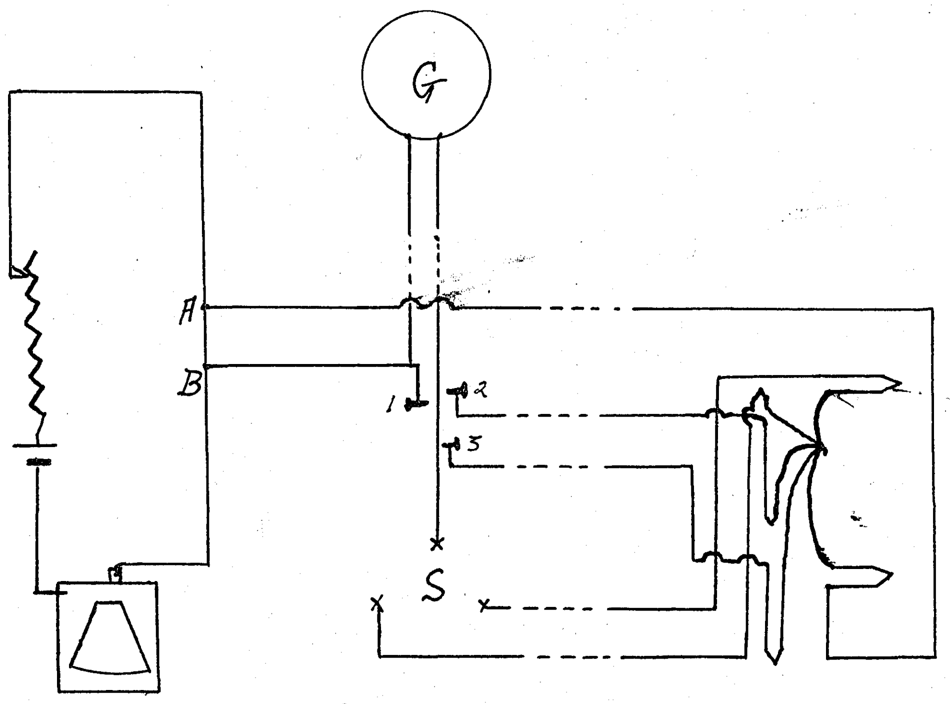


Fig. 3

connection with the present work a recheck was made of the instrument. With the same instrument reading, after allowance had been made for a slight shift in the zero, the potential drop across 200 ohms was found to be 1.5675 volts, indicating a current of .0078375 amperes. No further check was considered necessary.

Calibration.

For calibrating the thermo couples two Beckmann thermometers of about 6° range and with scale divisions of hundredths of a degree were used. The first step in the calibration was to compare the Beckmanns with each other and with a standard thermometer. The "standard" was one of a set of five certified by the U. S. Bureau of Standards. The two Beckmann's were tested over a range of more than 5 degrees. When the curves of the readings of the two were plotted both gave straight lines with a maximum departure of 0.015°. From the curves, also, a temperature change of 5° C as indicated by the standard thermometer was represented as 4.955° C on one Beckmann and 4.970° C on the other. The departure from the standard was not important since differences in temperature rather than actual temperatures were to be measured. The two Beckmanns thus showed themselves to agree to within 15 parts in about 5,000, which was considered good enough. The possibility of a constancy in cross section of the capillary bore in the thermometer sufficient to account for such agreement is almost beyond belief.

The actual calibration of the two important junctions was

~~was~~ the next step in order. Due to mishaps involving the breaking of junction wires and def/ective junction plugs, this phase of the work was repeated until the experimenters achieved a considerable degree of proficiency in the operation. The calibration was obtained by placing the bulb of a Beckmann thermometer in oil in a Dewar flask with each of the gas-path junctions and noting the Weston instrument readings necessary to balance the emf's produced by indicated differences of temperature. Fig. 4 shows the result of the last two calibrations. The almost perfect agreement of the two determinations made of different junctions but from the same spools of wire, demonstrates the reproducibility of the junctions without question. The fact that the curve does not pass through the origin is due to the fact that an approximate value of the "natural difference" in the readings of the two Beckmann thermometers was used instead of the exact value. The working curve should, of course, pass through the origin and should be parallel to the experimental one.

For the purpose of correcting for error in the galvanometer zero, the relation between galvanometer deflections and Weston instrument readings was found. With a current flowing through the potentiometer wire, the Weston instrument read 12.4. The resulting deflection of the galvanometer was 17.5. One division on the instrument scale was therefore equivalent to 1.4 cm. on the galvanometer and 1 cm. on the galvanometer to .7 division on the ammeter.

Temperature differences - degrees
Weston Instr Readings - Scale divisions
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
20
40
60
80
100
120
140
160
○ First Calibration
× Second Calibration

Fig 4

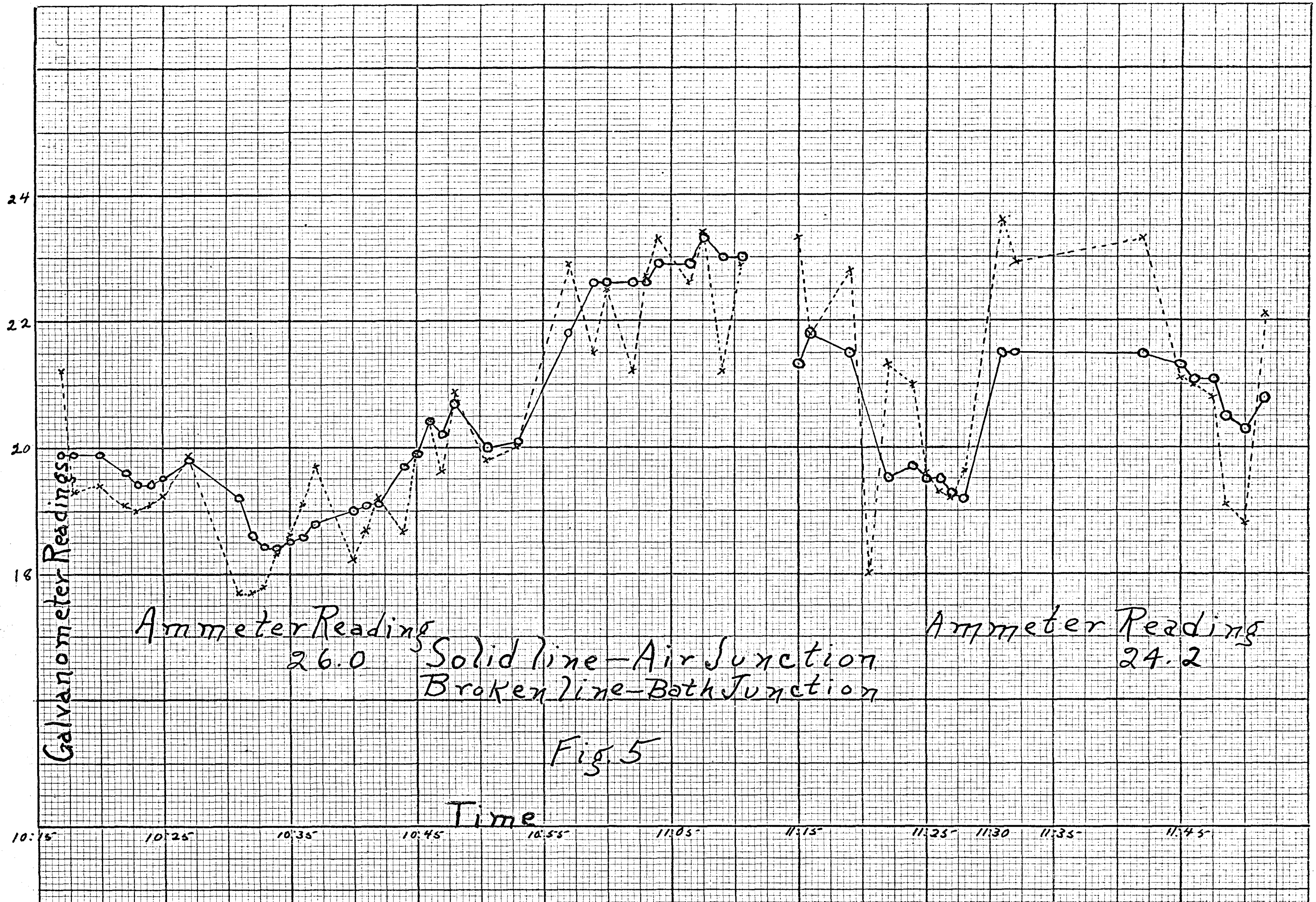
Procedure

After the calibration of the junctions, they were placed in their positions in the nozzle, the bath containers were put in place and filled with kerosene and the entire apparatus was tested for leaks. In preparing for a "run", the compressor was started and air was pumped in from the outside until a pressure of somewhere near 100# was indicated by the gauge connected to the lower large cylinder. Then the valves were changed so that the compressor pumped the air from the low pressure tank into the high pressure one. The needle valves were then opened and air was allowed to pass through the plug. After a short time the pressure below the plug could be brought to a steady value as indicated by the indicating gauge. Then the pressure between the two sides of the plug as indicated by the mercury manometer could be adjusted to the value desired. During most of the determinations the pressure below the plug was kept at 40# and the difference in pressure at one atmosphere. Little difficulty was experienced in keeping the pressure and pressure difference practically constant over long periods of time.

Far greater difficulty was experienced with the temperature controls. The thermocouples and the accompaning measuring devices made it possible to detect temperature changes of the order of 0.001°C. but the means at hand for controlling the bath temperatures proved inadequate for such delicate adjustments. The water bath comprised such a large bulk of water that its temperature remained practically constant for any ordinary experimental period. The lower oil bath, likewise, from its intimate thermol contact with the water through the copper container maintained a fairly constant temperature. In spite of the length of coil in the water, however, the temperature of the lower gas junction rarely checked exactly with those of the baths. These lower baths were highly satisfactory, however, in comparison with the upper oil bath.

It was discovered early in the game that a very intimate relation existed between the temperature of the upper bath and the upper gas junction. The cause of this relation is still a matter for conjecture. A copper tube through which ice water could be circulated and a heating coil were provided to control the bath temperature. The flow of ice water was controlled very nicely by a needle valve and the heating coil by a lamp rheostat containing lamps of various sizes. All of the runs attempted were at or near room temperature.

After air had been passing through the plug for some time and steady pressure conditions had been secured, the attempt was made to bring the temperature of the upper bath to that of the upper gas junction. It was found that the temperature change indicated by the upper junction depended in very large degree upon the temperature of the upper bath. Figure 5 shows graphically the behavior of the junctions in the upper gas path and in the upper bath during a particular run. The graph shows the galvanometer readings plotted against time. The potentiometer current was not varied and the galvanometer readings are thus made an indication of the temperature variations. The right hand part of the graph was made from data taken with a new ammeter setting since the readings were getting inconveniently far away from the galvanometer "zero" which was 19.7. Table No. 1 shows the data from which the graph was made.



24
22
20
18
Galvanometer Readings
Ammeter Reading 26.0
Solid line—Air Junction
Broken line—Bath Junction
Ammeter Reading 24.2
Time
10:15
10:25
10:35
10:45
10:55
11:05
11:15
11:25
11:30
11:35
11:45

Fig. 5

TABLE I

Data showing effect of upper bath temperatures changes on Upper gas-path junction.

8-8-28 Time	Gal. Readings Air	Bath	Weston Readings
10:17	19.9	21.2	26.0
10:18	19.9	19.3	26.0
10:20	19.9	19.4	26.0
10:22	19.6	19.1	26.0
10:23	19.4	19.0	26.0
10:24	19.4	19.1	26.0
10:25	19.5	19.2	26.0
10:27	19.8	19.9	26.0
10:31	19.2	17.7	26.0
10:32	18.6	17.7	26.0
10:33	18.4	17.8	26.0
10:34	18.4	18.3	26.0
10:35	18.5	18.6	26.0
10:36	18.6	19.1	26.0
10:37	18.8	19.7	26.0
10:40	19.0	18.2	26.0
10:41	19.1	18.7	26.0
10:42	19.1	18.7	26.0
10:44	19.7	18.6	26.0
10:45	19.9	19.9	26.0
10:46	20.4	20.4	26.0
10:47	20.2	19.6	26.0
10:48	20.7	20.9	26.0
10:50½	20.0	19.8	26.0
10:53	21.0	20.0	26.0
10:57	21.8	22.9	26.0
10:59	22.6	21.5	26.0
11:00	22.6	21.2	26.0
11:02	22.8	22.8	26.0
11:03	22.6	22.7	26.0
11:04	22.9	23.3	26.0
11:06½	22.9	22.6	26.0
11:07½	23.3	23.4	26.0
11:09	23.0	21.2	26.0
11:10½	23.0	22.9	26.0

TABLE I (Cont'd)

Time	Gal. Readings Air	Bath	Weston Reading
	Galvanometer Zero 19.7		
11:15	21.3	23.3	24.2
11:16	21.8	21.8	24.2
11:19	21.5	22.8	24.2
11:20	19.6	18.0	24.2
11:22	19.5	21.3	24.2
11:24	19.7	21.0	24.2
11:25	19.5	19.6	24.2
11:26	19.4	19.3	24.2
11:27	19.3	19.2	24.2
11:28	19.2	19.6	24.2
11:31	21.5	22.9	24.2
11:42	21.5	23.3	24.2
11:45	21.3	21.1	24.2
11:46	21.1	21.0	24.2
11:47½	21.1	20.8	24.2
11:48½	20.5	19.2	24.2
11:50	20.3	18.8	24.2
11:51½	20.8	22.1	24.2

Every possible method of approach to equilibrium temperature condition was tried. The best that could be achieved was a variation of from 0.01°C to 0.05°C for periods of 5 to 7 minutes. The most discouraging feature of the results of these short periods of apparent equilibrium was their lack of agreement with each other. After three complete runs had been made each covering several hours of time and each representing the nearest approach to equilibrium conditions that could be obtained, the situation was considered hopeless. The values obtained after the reasonable corrections had been made were 0.299°, 0.266° and 0.226° for practically the same pressure and temperature conditions. The pressure was held at 40#, the difference of pressure at 1 atmosphere and the temperature of the water bath varied from 26.2°C in one case to 27.2° in another. Table 2 shows a summary of these runs.

The apparatus was then dismantled for examination. Upon examination of the nozzle, it was found that oil had leaked in through the threads where the two fiber parts had been screned together. A path through which oil could flow would of course permit air to pass. It was possible then that a considerable portion of the air passing through the nozzle did not pass through the plug at all. This was of course unintentional and perhaps highly undesirable, but does not explain reasonably the intimate control between the upper bath and the upper junction. A previous investigation of the rate of flow through the nozzle showed a velocity of about 28 cm. per second. A determination by Dr. Kester with the inner fiber tube and plug alone showed a rate of flow

TABLE II

Time 8-6-28	Gal. Reading Air	Bath	Weston Inst. Read.	Corrected
3:48	19.75	20.7	28.5	28.9
to				
5:14	Zero	19.8		
5:14	20.2	20.7	28.4	28.6
to				
6:20	Zero	20.1		

Pressure 40# - Pressure Difference 75.9

Temperature 27.0 C

8-7-28				
9:30	19.9	19.8	27.9	27.9
to				
10:42	Zero	19.9		

Pressure 40# - Pressure Difference 75.7

Temperature 27.2° C

8-8-28				
9:51	19.2-21.5	18.0-23.3	24.2	24.2
to				
11:51				

Pressure 40# - Pressure Difference 75.9

Temperature 26.2 C

about five sevenths as great. That leaves two sevenths of the entire flow to be accounted for by the intended leak through the string packing in the annular space surrounding the inner tube and by the unintended leak through the screw threads of the plug. Even that does not seem to be enough to explain the difficulty of temperature control.

At this stage the school term closed. It was decided to pack the joint of the fiber nozzle and attempt a new determination of the Joule-Thomson effect. A new cotton plug was put in and the screw joint of the nozzle packed with rubber packing. A test of the rate of air flow through the new plug showed a velocity of about 20 cm. per sec. It had been hoped that the rate of flow would be greater than for the old plug but the test showed otherwise.

Two runs were made with the rejuvenated apparatus. It was decided to try a system of one-man operation. That is, the observer at the galvanometer was to make the necessary change in the flow of ice water or in the current through the heating coil. An improvement in the regulation was apparent. The gas path junction also seemed to be less under the control of the temperature of the upper bath. Table 3 shows the complete data on the run manipulated by the writer at a pressure difference of about one atmosphere.

An attempt was then made to check on the linear relation that has been repeatedly proved to exist between pressure difference and temperature charge. The attempt was a failure although a balance between bath and gas temperatures was quickly obtained and maintained within reasonable limits for considerable periods of time. Two determinations at different pressure differences were made, one at 50.1 cm. Hg. and one

TABLE III

Time 8-16-28	Gal. Readings Air	Bath	Weston Instr.
1:50	Zero	19.2	
1:59	19.2	17.7	28.2
2:02	20:5	18.3	28.2
2.07	18.7	20.0	28.2
2:09	19.2	21.6	28.7
2:12	19.2	21.7	28.4
2:16	19.2	22.2	29.0
2:19	19.2	24.1	29.0
2:22	19.2	24.3	29.0
2:29	19.2	19.6	29.1
2:32	19.2	19.7	29.0
2:34	19.2	20.0	29.0
2:35	19.3	20.9	29.0
2:37	19.7	22.5	29.0
2:39	19.2	19.9	28.5
2:41	19.4	20.7	28.5
2:43	19.2	20.5	28.2
2:45	19.2	19.0	28.2
2:48	19.6	22.0	28.2
2:50	19.4	17.4	28.2
2:53	19.5	17.5	28.2
2:57	19.2	19.2	27.7
2:59	19.2	20.7	27.7
3:01	19.5	22.8	27.7
3:02½	19.9	22.5	27.7
3:04	19.7	19.9	27.7
3:06	19.2	17.5	27.5
3:09	19.0	20.0	27.5
3:13	18.9	19.0	27.5
3:16	19.2	21.0	27.7
3:18	19.3	20.8	27.7
3:20	19.4	19.0	27.7
3:22	19.2	20.0	27.5
3:24	19.2	20.4	27.5
3:25	19.4	18.1	27.5
3:26	19.2	19.2	27.5
	Zero	19.3	

Pressure 38# - P. D. 74.2 cm. Hg.
Key 2 (without Potentiometer current) 37.3
Key 3 35.7

at 94.8 cm. Hg. No explanation occurs to the writer to account for the values obtained. For the 50 cm. pressure the linear relationship would indicate a Weston instrument reading of 18.8 whereas the reading actually obtained was 21.0. For the 95 cm. pressure the linear relationship indicates a reading of 35.1 but the actual reading was 32.0. Conditions seemed very favorable for reliable readings.

The surprising thing, however, was that when a return to the one atmosphere pressure was made a reading of 27.7 was obtained. It may be said very positively that the three values obtained on this last day's run agree with each other better than any formerly taken. Dr. Kester obtained a reading, after more than 2 hours manipulation, of 27.0 for a pressure difference of 74.2 cm. The writer's first reading with the same pressure difference was 27.5. The second with a pressure difference of 75.7 cm. was 27.7. If correction is made for different pressure differences the last reading would be 27.2. The average of the three determinations is 27.23.

From the calibration curve, Fig. 1, it may be seen that the relation between instrument readings and temperature difference is almost exactly as 15 is to 14 if temperature differences are in hundredths of degrees C. Using this relation then gives us 14/15 x 27.2 or 0.254°C at a pressure of 74.2 and a water bath temperature of 26.5°C. This corresponds to a value of 0.26°C at a difference of pressure of one atmosphere. Roebuck obtained a value of 0.227°C at 25°C while Hoxton's value is about 0.25°C at 20°C. Further comparisons are impossible with the limited temperature and pressure ranges used in this work and from the data given by the other observers.

Discussion of difficulties.

A number of changes in the design and construction of the apparatus will no doubt be necessary before reliable results will be impossible. In the opinion of the writer, the changes should provide; (1) Greater velocity of gas flow through the plug. (2) Better thermal insulation between the gas path and the surrounding metal. (3) Greater volume of liquid for the upper bath so that its temperature would be less susceptible to the room temperature and to other thermal disturbances.

If it were possible to eliminate metal altogether from the vicinity of the plug, most of the difficulty would probably be eliminated. This might be approximated by making the nozzle much larger than the present design. Conduction of heat by the brass of the nozzle is probably a serious source of difficulty. In all determinations the temperature of the lower gas path junction was found to be appreciably different from that of the surrounding baths. The only possible explanation of such phenomena seems to be conduction between that junction and the upper bath.

In the mind of the writer, however, there will always remain a doubt that heat conduction by the brass could affect a moving gas stream sufficiently to account for the heat control difficulties met with in this work. The thermal conductivities of the red fiber and perhaps of the small bakelite plugs should be subject to suspicion.

The writer has abundant faith in the experimental ability of his associate in this work and sincerely hopes that the time taken from his vacation this summer may eventually result in some reliable values for the Joule-Thomson effect in air and other gases. It has been a great pleasure to have worked with Dr. Kester in this research and, while the direct results seem inconclusive and perhaps unimportant, a great many things have been learned that cannot be set down here. Perhaps, after all, that is the chief value in research.

University of Kansas

August, 1928.